Agricultural Practices Contributing to Aquatic Dead Zones

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Contents

17.1 Introduction 374
17.2 Global Occurrences of Dead Zones 376
17.2.1 The Gulf of Mexico Dead Zone 378
17.3 Sustainable Solutions to Dead Zones 385
17.4 Conclusion 390
References 391

Abstract

Aquatic dead zones are areas of decreased biodiversity due to hypoxic conditions. Runoff from farms often contains high levels of nutrients, particularly nitrogen and phosphorus, which flows into larger bodies of water and eventually the ocean and stimulates algal growth. When the algae die, they settle to the bottom and are decomposed by bacteria. The amount of oxygen produced by photosynthesis is exceeded by the amount of oxygen consumed during decomposition, thus leading to hypoxia in the bottom waters. This low oxygen starves organisms such as fish and shellfish, leading to decreased biodiversity or extinction of animal life in the area. Dead zones are linked to agricultural activity and are growing, which poses a threat to both aquatic organisms and humans. In this chapter, the case of the Gulf of Mexico dead zone is elaborated and sustainable solutions are posed to help mitigate this growing problem. The US "baby boom", a marked population increase, directly impacted the farming industry, and larger industrial farms have since been used to supply the buyers' needs. These farms use practices that are not sustainable

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K. Bauddh et al. (eds.), *Ecological and Practical Applications for Sustainable Agriculture*, https://doi.org/10.1007/978-981-15-3372-3_17

including planting monoculture crops that have poor nutrient absorption, planting crops that alter the soil composition causing increase flooding, and using chemical fertilizers. By identifying the source of the nutrients that cause dead zones, more sustainable solutions have been identified to stop the growing areas of hypoxia. Larger industrial farms are directly influencing the size and continual growth of the dead zones. Sustainable farming practices benefit both the consumers and aquatic ecosystems, and this chapter gives practical solutions for sustainable agriculture.

Keywords

Farming · Nutrients · Dean zones · Sustainable practises

17.1 Introduction

The creation of dead zones by hypoxia, a lack of oxygen in the water, is a growing ecological concern, and preventing their formation takes knowledge and effort from numerous parties. This chapter discusses the nature of dead zones and the sources of the nutrient input, with a primary focus on the influx of nitrogen and phosphorus from plant agriculture. The case study that is further analyzed is the dead zone in the Gulf of Mexico, where the various causes and negative effects of the occurrence are analyzed. Finally, this chapter will look at the ways farmers in the Mississippi River and other watersheds contribute to dead zones and can act more sustainably to prevent dead zone formation.

While the passage of the Clean Water Act in 1972 has made vast improvements in preventing the pollution of toxic materials into the rivers and lakes, two pollutants remain ubiquitous in America's and other countries' bodies of water, that is, nitrogen and phosphorus (Manuel 2014). These "pollutants", are not like those traditionally thought of in the sense they are not inherently toxic. In fact, the presence of nitrogen and phosphorus in ecosystems is essential. Nitrogen and phosphorus are needed to make cellular components such as proteins, DNA, cell membranes, and ATP, the energy currency of the cell. Without access to these, life would cease to exist. However, from an ecological perspective, the overabundance of these nutrients can be disastrous. As levels of nitrogen and phosphorus increase in aquatic systems, excessive algal growth called "blooms" occurs. The presence of algae is normally not negative; these photosynthetic microscopic organisms play an important role, that is, as the base, of aquatic food chains. However, too much of a good thing can become bad.

As the number of algae dramatically increases due to an increased provision of nutrients, termed by scientists as eutrophication, a whole host of problems begin to occur (Simmon 2019). Together, these problems form ecological "dead zones", areas where aquatic life and biodiversity are greatly reduced. The primary reason dead zones occur is that as algal levels increase, oxygen levels dramatically decrease, creating a condition called hypoxia in which nearly all aquatic life is incapable of tolerating (Manuel 2014). There are several ways excessive algal presence leads to a depletion of oxygen. For one, the higher rates of algae reproduction create higher rates of death and decomposition of algae. When this happens, dead algae

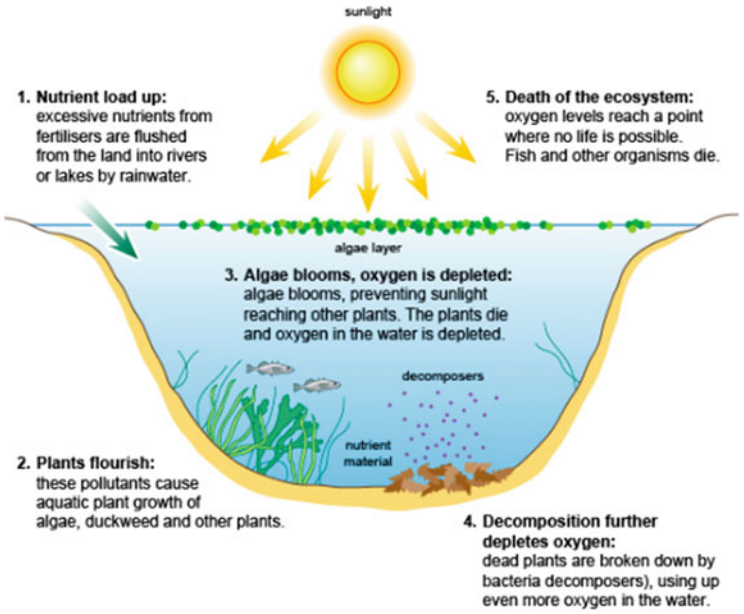
sunlight
1. Nutrient load up:
excessive nutrients from fertilisers are flushed from the land into rivers or lakes by rainwater.
5. Death of the ecosystem:
oxygen levels reach a point where no life is possible. Fish and other organisms die.
algae layer
3. Algae blooms, oxygen is depleted:
algae blooms, preventing sunlight reaching other plants. The plants die and oxygen in the water is depleted.
decomposers
nutrient material
2. Plants flourish:
these pollutants cause aquatic plant growth of algae, duckweed and other plants.
4. Decomposition further depletes oxygen:
dead plants are broken down by bacteria decomposers), using up even more oxygen in the water.

Fig. 17.1 Eutrophication (https://www.mrgscience.com/ess-topic-44-water-pollution.html)

accumulate at the bottom. Bacteria and fungi begin the decomposition process. As decomposition occurs, oxygen is utilized by the heterotrophic decomposers and carbon dioxide is released, depleting the available oxygen for other organisms (Rutledge et al. 2011). Additionally, the scum algae can form on the surface of the water and block out the sunlight necessary for the algae at depth, preventing photosynthesis and the release of oxygen. These plants are often what contribute significant amounts of oxygen to the water (Rutledge et al. 2011). A simplified diagram and explanation of this process is shown in Fig. 17.1.

While the accumulation of algae in general is harmful, there are certain kinds of algae that cause additional problems beyond just contributing to hypoxia. The major algal groups are cyanobacteria, green algae, dinoflagellates, coccolithophores, and diatoms. Increases in phosphorus and nitrogen input affect especially cyanobacteria, which are not as commonly consumed by other marine organisms (Rea and Patel 2017). Because of anthropogenic cultural eutrophication, more than 40% of the world's lakes and reservoirs in America, Asia, and Europe now host favorable conditions for the mass development of cyanobacteria. These organisms can cause a host of problems because "many cyanobacterial species are capable of synthesizing a wide range of odors, noxious compounds, or potent toxins" (Bláha et al. 2009). The toxins that are produced by 25–75% of the cyanobacterial algae pose serious threats to aquatic and human health (Bláha et al. 2009). Cyanobacteria are primarily known

for causing problems in freshwater systems; however, certain species of cyanobacteria can thrive in saltwater environments and cause problems.

Dinoflagellate overgrowth in marine bodies of water experiencing dead zones from nutrient input can also pose a problem. Dinoflagellate blooms, or "red tides", have an abundance of one kind of dinoflagellate, *Karenia brevis*, that turns the surface of the water red due to its red pigment (Hall 2018). Like cyanobacteria, these organisms produce toxins that can harm the marine and human life that comes in contact with them (Hall 2018). More of the harmful effects of these specific organisms are discussed later in this chapter in the case study of the dead zone in the Gulf of Mexico, where these organisms have created numerous ecological problems: besides cyanobacteria and dinoflagellates, other algal species are capable of producing toxic substances that can infiltrate the food chain and endanger the surrounding life.

So where is all the nitrogen and phosphorous coming from? There are plenty of natural sources; the nutrients are commonly found in soil, water, and, in the case of nitrogen, the air we breathe (Manuel 2014). There are also anthropogenic sources that are what have been the main culprits behind dead zones. In agriculture, nitrogen and phosphorus runoff comes from chemical fertilizers and manure from animal farms (EPA 2017). Nitrogen input can also come from legume crops planted near watersheds due to the nitrogen fixation that occurs in their root nodules. In urban areas, nutrient pollution can be the result of wastewater treatment plants, failed septic tanks, storm water draining, pet waste, and fertilized home gardens (EPA 2015). Industrial waste and air pollution can also contribute to nutrient problems in dead zones.

17.2 Global Occurrences of Dead Zones

Dead zones are a global phenomenon; according to a 2008 study, there are over 400 dead zone occurrences around the world (Simmon 2019). Some of the most prominent ones reside in the Chesapeake Bay, the Baltic Sea, and the Gulf of Mexico.

The Chesapeake Bay was one of the first dead zones ever discovered and has contained a dead zone since the 1970s (Rutledge et al. 2011). Chesapeake Bay dead zone is caused by excessive levels of nitrogen stemming from urbanization west of the bay and agriculture toward the east. Many factories located in the well-developed area west of Chesapeake eject copious amounts of nitrogen pollution into the air. This type of pollution is responsible for about one-third of all the nitrogen found in the bay. The east side of Chesapeake Bay is a hub for poultry farming, which generates significant amounts of nitrogen-rich manure. Despite numerous efforts by the Chesapeake Bay Foundation to rid the bay of pollutants, Chesapeake Bay dead zone still exists today (Erickson 2018). As of the summer of 2018, researchers from the University of Michigan and the University of Maryland Center for Environmental Science expected the size of Chesapeake Bay dead zones to cover a volume of 7.9 cubic kilometers, with about 22% of that volume predicted to be

anoxic, that is, severely deprived of oxygen (Erickson 2018). The study echoes the findings of Rutledge and her team, arguing that Chesapeake Bay dead zone is primarily caused by excess nutrients that flow into the bay. According to Don Scavia, an aquatic ecologist and professor emeritus of sustainability at the University of Michigan, the dead zone in the Chesapeake Bay is significantly larger than the goal set by the Chesapeake Bay Total Maximum Daily Load agreement. A 10-year study of the Chesapeake Bay's fishes by researchers at the Virginia Institute of Marine Science found a drastic decline in species richness, species diversity, and catch rate under the dead zone's low-oxygen conditions. This was especially true for the demersal fish that lived near the bay's floor (Buchheister et al. 2013).

As troubling as the Chesapeake Bay dead zone is, hypoxic conditions in the Baltic Sea are proving to be even more catastrophic. As of the summer of 2018, the dead zone in the Baltic Sea covers an area of about 70,000 square kilometers (Davis 2018), which constitutes about 19% of the entire Baltic Sea. According to scientists from Finland and Germany, the Baltic Sea's dissolved oxygen levels have hit a 1500-year low after a notable decrease in marine oxygen over the last century (Davis 2018). These researchers used sediment cores obtained from the Archipelago Sea, a portion of the Baltic Sea off the coast of Finland, and tested the cores using chemical proxies, as historical oxygen levels cannot be directly measured (Duncombe 2018).

Data collected from the sediment cores revealed that dead zones existed during the Middle Ages, specifically during the Medieval Warm Period from 900 to 1350 AD. Warm water retains less oxygen compared to colder water. Despite hotter than average temperatures during the period, evidence of hypoxia on the coasts was much less pronounced than it is today, indicating that modern-day dead zones are not merely a result of natural causes or even global warming. Human activity in agriculture and industry appears to contribute significantly to hypoxic conditions in the Baltic Sea today.

The study also found evidence of dead zones near the beginning of the twentieth century, and the sediment record shows that the Baltic Sea's oxygen levels have consistently decreased ever since. Even more worrisome is the fact that species that inhabit the seafloor are completely disappearing as a result of the declining oxygen levels. Joonas Virtasalo, a member of the research team from the Geological Survey of Finland, describes an alarming finding: "The seafloor is completely devoid of macrofauna for the first time in our studied record." This discovery has been confirmed through field observations and careful monitoring of the research site. While neighboring pockets of the Archipelago Sea still contain enough oxygen to sustain life, the study warns that oxygen is quickly depleting in coastal waters, particularly near the seafloor. The scientists conclude that human activity, particularly excess nutrient runoff, has magnified the size and severity of dead zones, which are already growing because of climate change.

Despite the study's discouraging findings, efforts are continually being made to reduce fertilizer runoff and combat the rampant growth of dead zones in the Baltic Sea. One such effort in Stockholm, Sweden, to reduce nutrient pollution has proved successful in reversing the dead zones humans have created in the surrounding waters. However, it is clear that much more needs to be accomplished before any

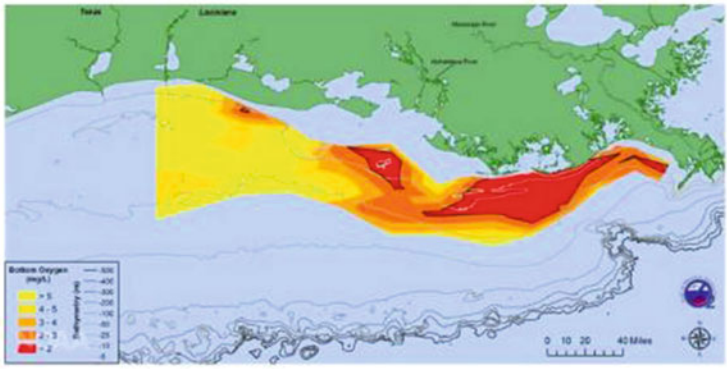

Fig. 17.2 Extent of the Gulf dead zone (USEPA 2019)

change in the dead zone size or severity is achieved. Sami Jokinen, the lead author of the Biogeosciences study, calls for an even greater level of action: "To achieve good ecological status in coastal areas under the projected global warming, the required reduction in nutrient input might be higher than previously thought" (Duncombe 2018).

17.2.1 The Gulf of Mexico Dead Zone

One of the world's largest and most costly dead zones has been the Gulf of Mexico dead zone (Fig. 17.2). This dead zone was first noted by shrimp trappers in the 1950s; however, it was not until the 1970s that scientists began investigating and documenting the phenomenon (Rea and Patel 2017). Today, the Gulf of Mexico has the largest dead zone in the United States. In the summer of 2017, it spanned over 22500 km^2, roughly the size of New Jersey (Belva 2017). Satellite imagery shows a great span of the zone because the nutrients are often carried in the sediments that are dumped into the Gulf, which is another issue by itself (Fig. 17.3). Figure 17.4 depicts where the Neuse River, part of the Mississippi River watershed, meets the ocean waters and shows the severity of the nutrient-containing sediment from the upstream entering the ocean (Chohan 2007). The Gulf of Mexico dead zone occurs every summer due to nutrient pollution from the Mississippi River watershed (EPA 2019a, b). The zone has varied in size throughout history. For instance, in 1988, a time of severe drought, the zone seemed to be nearly gone, but in 1933, a year of intense flooding, the zone expanded nearly 7800 km^2 (Rea and Patel 2017).

Nutrient loading from the Mississippi into the Gulf is a major factor, which increases the number of nitrates and phosphates in the water. A trend can be drawn between the influx of these nutrients and the seasonal increase of phytoplankton production, which is quite large (Courtney and Courtney 2015). The fertilizers used for everything from beets to wheat and corn in Minnesota, Illinois, Kansas, and Iowa are not entirely absorbed by the soil for usage in farming, the excess washes

Fig. 17.3 Satellite image of the Gulf of Mexico dead zone in 2009 (NASA Earth Observatory (2019)

Fig. 17.4 Expanse of the Mississippi River watershed (US Geological Survey 2000)

away with rain and irrigation (Davis 2017). It then flows into a nearby body of water that ultimately flows into the Gulf of Mexico. Warmer temperatures of other bodies of water, including the Great Lakes, have led to prolongation of warmer seasons and increased stratification in the water (Salt Water Sportsman 2019).

The dead zone in the Gulf of Mexico has arisen from an excessive influx of nutrients, and the algae which thrive from these nutrients have 'bloomed', and the

increased rate of bacterial decomposition of the algal biomass uses up the oxygen in the water. The leaves deoxygenated, eventually forming hypoxic areas where fish suffocate and die. In addition, after the phytoplankton bloom in response to the nutrient overloading, they die and sink to the bottom of the body of water. The algal blooms on the surface also decrease the light penetration to the Gulf bed and deprive the lower dwelling plants of light. The decomposition of bacteria consumes oxygen and generates carbon dioxide that further stifle the fish (Davis 2017). Hypoxic zones are somewhat mitigated by the tropical storms in the summer in areas such as the Louisiana–Texas shelf, which mix the warmer surface layers of water that are well-oxygenated and stratified with the cooler oxygen-starved bottom layers (Courtney and Courtney 2015). This natural mitigation, however, can only do so much in terms of reduction of the dead zone because of the increase influx of nutrients.

The expanse of the Mississippi River watershed is greater than what many people think. Figure 17.4 shows the expanse of the watershed and how the deleterious effects of nitrogen and phosphorus often occur hundreds or thousands of kilometers from where the nutrients originate (Manuel 2014). These areas contain some of the states with the highest corn, soy, and potato production. Major contributors to this Mississippi River basin (MRB) include the Ohio and Upper Mississippi River basin watersheds that all lead into the Gulf of Mexico. Within the Mississippi River watershed, there are three main sources of nutrient input: urban, natural and agricultural runoff. For nitrogen contributions in this watershed, about 14% are from urban sources, 26% from natural sources, and 60% from agriculture. About 49% of phosphorus originates from agriculture, 29% from urban sources, and the remainder from natural sources (Fig. 17.5).

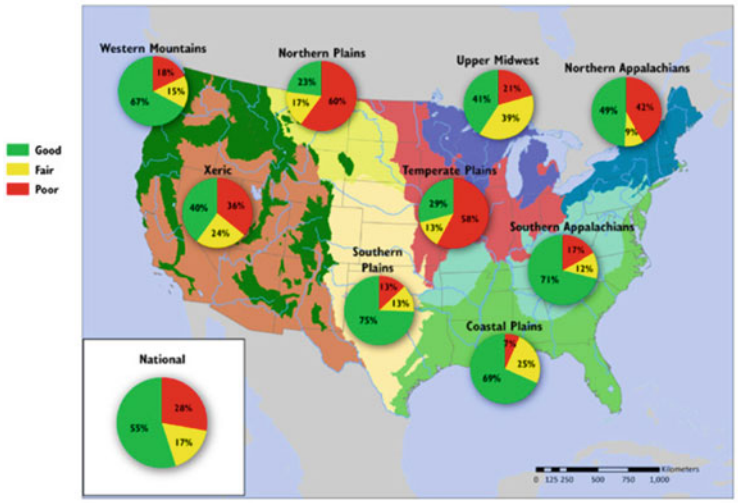

Fig. 17.5 Nitrogen pollution in US rivers and streams (Manuel 2014)

As shown in previous statistics, agriculture in particular has played a major role in nutrient pollution in the Mississippi River watershed, which dumps directly into the dead zone in the Gulf of Mexico. In the mid-to-late 1900s, there was a major population boom in the United States, and with this came an increased demand for crop production and yield (Davis 2017). Due to developments in technology as well as land use changes in agriculture in the United States, agricultural production value has nearly doubled since the baby-boom era (Talis 30). With this increase in value and demand have come new agricultural practices that contribute to nutrient pollution and dead zone formation.

An interesting trend to note in Fig. 17.6 includes the change in farm composition from the 1850s to 2017. There was a large peak that occurred around 1910–1954, which coincides with the population increase (USDA 2015). In addition, the overall land dedicated to farms since the 1930s has stayed roughly the same, if not decreased. What has changed is the average farm size. The data published by the USDA shows the transition from a large quantity of smaller farms to a smaller amount of larger, or industrial, farms. Corporations which run and fund these are not always as environmentally conscious.

One contributing factor to the worsening conditions of nutrient pollution and runoff in the Mississippi River watershed has been the conversion of natural prairie

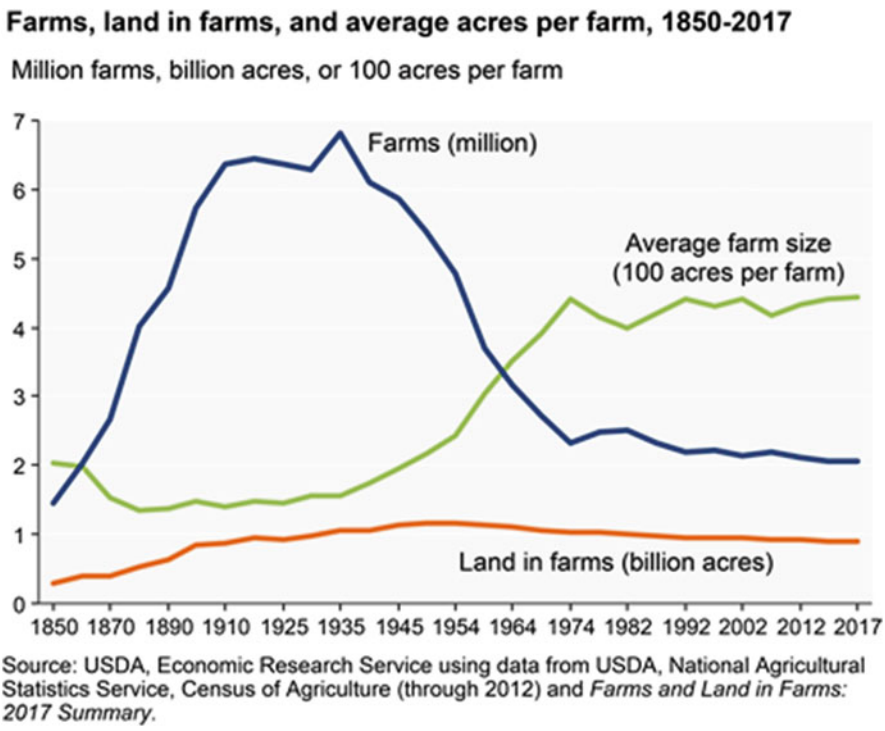
Farms, land in farms, and average acres per farm, 1850-2017
Million farms, billion acres, or 100 acres per farm
Farms (million)
Average farm size
(100 acres per farm)
Land in farms (billion acres)
0
1
2
3
4
5
6
7
1850 1870 1890 1910 1925 1935 1945 1954 1964 1974 1982 1992 2002 2012 2017
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Census of Agriculture (through 2012) and Farms and Land in Farms: 2017 Summary.

Fig. 17.6 Average acres per farm in the USA (USDA 2015)

lands and forests surrounding the basin into farmland and urban centers. Inorganic farming, pesticides and other chemical fertilizer usage, and the transition from diverse and runoff-adapted polycultures (areas of plant diversity) to more monocultures (areas where one plant (i.e., corn) dominates) are all factors affecting these basins. Agricultural lands, which predominantly influence the basin, almost entirely rely on inorganic farming. Inorganic farming, a practice that causes more nutrient runoff, relies on mineral fertilizers (MF) over biosolids to catalyze the growth of plants (Wallace et al. 2013). MF includes a larger concentration of nutrients than biosolids that are primarily sourced from natural causes. A study done by the University of Reims Champagne-Ardenne tested the effects of switching from inorganic farming to organic, and the results were in favor of organic farming. The study focused on the use of MF or biosolids and the conclusion drawn was that MF contributed to larger nutrient loads despite runoff-preventing irrigation methods being used (Morvan et al. 2018). The study promotes the agricultural practice of organic fertilizer, yet farmers continue to use conventional fertilizer. As fertilizer use has increased sevenfold due to this increasing demand on agriculture, nitrate runoff has tripled, which ends up in the Mississippi River basin (MRB) (Tallis et al. 2019).

Additionally, the root systems of annual agriculture products such as corn and soy are significantly less extensive than those of the prairie grass and trees that previously dominated. A lot of current agricultural land in the United States was prairie land filled with deep-rooted tall grass, now replaced with primarily corn and soybeans. The roots of corn and soybean are significantly shallower and are not present for large portions of the year after harvesting. However, the original prairie grasses and trees maintain their deeper and stronger root systems throughout the year (Gallegos 2017). Larger roots such as those of the native prairie grass have the ability to take up more water and a higher percentage of nutrients into the plants for the process of photosynthesis, leaving less water remaining in the topsoil. The properties of corn and soybeans can inhibit rainfall and water sources from leaching into the ground because of their shallow roots and only having growth for parts of the year, leading to higher rates of flooding. The higher the occurrence of flooding, the more often nutrients will be found in water supplies because of the increased runoffs (Davis 2017).

Newer agricultural processes have also led to soil erosion and overall damage to the land (Morvan et al. 2018). Soil degradation involves the removal of topsoil, which causes a decline in soil quality on the chemical and biological level and leads to soil being transported to undesirable areas. Topsoil loss, especially in the Midwest, is an alarming issue with severe implications for the Gulf of Mexico dead zone. Figures 17.3 and 17.4 show the current degree of sediment dumping occurring in the Gulf. Conventional farming methods that focus on crop yield and short-term cost-effectiveness rather than soil preservation have harmed not only the future of agriculture in America but also the vital Gulf ecosystem.

Increased production of certain agricultural products has also led to rapid nutrient inflow into the Mississippi River basin. Corn in particular has been one major culprit because it allows more nitrate to come off the fields than any other crops, which is why it is termed a “leaky” crop (Davis 2017). Between the 1940s and 1990s, corn

production nearly tripled (Davis 2017). One reason for the increase is the multipurpose abilities of corn. Corn can be eaten plain, converted to a sweet corn syrup, or used for a source of food in the meat industry. In the past 70 years, there has been an increase of popularity for corn syrup in the American diet due to its sweetening capabilities. Additionally, increased meat production has indirectly led to increased corn production. In the early 1900s, farmers discovered that feeding cows corn, soy, and grain, rather than grazing on pastureland, can create greater yields and allow a greater supply of meat for the food market (Davis 2017). Instead of land being used solely for crops consumed by humans, an extra sum of land began to be used for crops consumed by cattle. Cassidy et al. (2013) estimates that nearly 36% of farmland today is utilized for feed crop. Ground beef companies such as ConAgra, Iowa Beef Processors, and Cargill, with headquarters located along the Mississippi River watershed, have adapted these practices to produce high quantities of beef. The companies even allocate land near the cattle farms for growing of cattle feed (Davis 2017). In more recent history, an alcohol derived from corn that is added to gasoline, that is, ethanol, has increasingly gained demand, through government subsidies. This has created a demand not just for corn to feed animals and humans but also for fuel.

However, corn is just one of the many crops that have seen a dramatic increase of production due to American demands. As the land in the Mississippi River watershed has been slowly converted from natural ecosystems to massive monocultures laden with chemical fertilizers, pesticides, and shallow-rooted plants, we have seen unprecedented levels of nitrogen and phosphorus in our rivers, streams, and now oceans. But just how harmful have these dead zones been to those near and dependent on the Gulf of Mexico?

The economic effects of hypoxic zones in the Gulf of Mexico are still largely unknown, but Smith et al. (2017) have provided valuable insight into the connection between dead zones and the economy, particularly concerning the shrimp industry. The study was done with the help of the National Oceanic and Atmospheric Administration (NOAA) and received funding from the National Centers for Coastal Ocean Science (NCCOS), a subgroup of the NOAA (2017). Lead author Martin D. Smith, an environmental economics professor at Duke University, explains the purpose of the study:

> Many studies have documented the ecological impacts of hypoxia, but establishing a clear causal link to economic losses in affected fisheries has been elusive. Our study does this by showing how seasonal hypoxia off the Louisiana and Mississippi coasts drives monthly fluctuations in market prices in the Gulf brown shrimp fishery, a major fishery that was once the most valuable in America.

Smith notes that finding a causal relationship between dead zones and fishery profits has proved particularly challenging because of the many feedbacks given by both human and environmental systems that interfere with the control areas, which makes it tough to establish any causality (Smith et al. 2017). The NCCOS study overcomes feedback contamination by using a market counterfactual, in which time

series models are used to construct a model of what the shrimp fishery industry would look like if hypoxic conditions were not present in the Gulf of Mexico. Thus, price fluctuations in resource markets such as shrimp are used to measure the impact dead zones have on the economy.

Smith and his team created a counterfactual market by pairing the ecological effects of hypoxic zones with a multi-market model that utilizes shrimp size to determine pricing. When using a naive model, the authors found no evidence that hypoxia causes price changes in shrimp markets because feedbacks in the human and ecological systems contaminate the control areas and obstruct any attempt at establishing causality. However, time series pricing models remove feedback pollution by implementing a counterfactual so causality can be easily measured using correlation coefficients.

As Gulf waters lose oxygen, large shrimp become more expensive as compared with their smaller counterparts. Even small changes in price of shrimp can produce massive ripple effects throughout the Gulf fishing industry, as shrimp accounted for $455,363,744 in 2017 alone, which constituted over 51% of all the revenue generated by the Gulf of Mexico fisheries (NOAA 2017). Dead zones pose not only ecological threats but also economic ones.

Decreased shrimp production is not the only sector harmed by nutrient pollution and dead zones. As mentioned before, nutrient input can lead to the blooms of multiple species of algae that can produce harmful toxins. Red tides formed by dinoflagellates in particular have caused problems in the Gulf of Mexico, especially near the Florida coast. *Kerenia brevis*, one of the algae responsible for red tides that is commonly found near the Florida coast of the Gulf of Mexico, produces a neurotoxin called brevetoxin that disrupts the firing of nerve cells. These toxins bioaccumulate up the food chain and harm many species including fish, seabirds, and marine mammals. For instance, during a 1996 bloom, 149 endangered manatees died off the coast of Florida, and during another bloom from 1987 to 1988, over 740 bottlenose dolphins died after eating contaminated menhaden fish that consume the algae (Hall 2018). One study done later collected many of these deceased animals and found abnormally high levels of brevetoxin in their tissues (Flewelling et al. 2005). The accumulation of these toxins reduces biodiversity, which greatly harms the health and stability of any ecosystem.

These toxins can also harm people. Humans are exposed to algal toxins through food, water, or air. The most common way individuals fall ill is through consuming shellfish, filter feeders that easily accumulate toxins (Fleming et al. 2011). Consuming shellfish with harmful dinoflagellate exposure can lead to neurotoxic shellfish poisoning (NSP) in humans. This severe acute disease often requires emergency room and intensive care during the first hours to prevent respiratory failure (Fleming et al. 2011). It is also concerning that there are currently no studies showing the long-term health effects on low levels of exposure that do not lead to NSP. Additionally, people can acquire respiratory problems from simply breathing near these tides. There have been numerous studies in asthmatics and non-asthmatics linking aerosol exposure to health issues (Fleming et al. 2011). For example, one study conducted in

the Gulf area found that lifeguards who were exposed to the tides experienced a statistically significant higher rate of respiratory health problems (Cheng et al. 2005).

Because of these harms to human health, there are many economic implications from having a dead zone present in the Gulf of Mexico. One of the major industries this affects is tourism. These organisms not only frighten beachgoers with illness but also produce an unpleasant odor. This can cause a large strain on coastal industries that depend on visitors coming to the area. Toxic algal blooms can also disrupt the fishing industry. As mentioned, contaminated shellfish can pose a significant health threat, causing fishers to be cautious about catching these creatures, especially during the summer months when the dead zone in the Gulf of Mexico gets bad. One alarming report found that "At present, harmful algal blooms cause about $82 million in economic losses to the seafood, restaurant, and tourism industries each year" (NOAA 2019). As shown, these dead zones are not just areas with unfavorable conditions that make "tree huggers" groan in discontentment: they are areas with serious and widespread harm to both aquatic and human life. They are areas where human health, recreation, seafood supplies, and biodiversity are all jeopardized.

17.3 Sustainable Solutions to Dead Zones

When analyzing how to mitigate dead zones and other ecological concerns, it is important to consider sustainability. In 1987, the UN World Commission declared that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Another often used and simplified definition encompasses meeting the needs for the people, planet, and profit. At the heart, sustainability involves finding a balance between each of these factors and will inevitably require give and take from the profit and planet side. Finding sustainable solutions to the Gulf of Mexico and other dead zones will not be a simple process. Nutrient pollution can come from natural, agricultural, municipal, and industrial sources, and tracking the source is not always easy. However, the process of eutrophication and dead zone formation is becoming an increasingly researched topic with more and more data and insight being released each year. There is hope for the Gulf and other dead zones, but it is going to take the input of all parties, including those involved in agriculture, to begin to see change.

One potential method for reducing nutrient pollution, especially in the Gulf, is the practice of sustainable farming. Sustainable farming aims at reducing fertilizer, using minimal tillage, and keeping the land as viable as possible. Two methods farmers use to reduce fertilizer and nutrients in the soil are alternating crops and using leaf biomass assisting composting both on and in the soil (Enger and Smith 2016). There are several benefits to using crop rotation, including improved soil tilth, nutrient cycling, improved soil physical properties, and enhanced weed control (Al-Khaisi 2001). Al-Khaisi, professor of Soil Science at Iowa State University, highlights the importance of crop rotation in nitrogen management, stating how "crop rotation can play a major role in minimizing the potential risk of nitrate leaching to surface and groundwater by enhancing soil N availability by reducing the amount of N fertilizer

applied, and by minimizing the potential risk of N leaching". This is because leguminous plants such as soybeans and alfalfa have symbiotic relationships with nitrogen-fixing bacteria in their roots, that is, after harvesting increased amounts of natural nitrogen will be available in the soil the next year. By rotating these sorts of crops with corn and grains, farmers can maximize nitrogen availability in their soil and reduce the need for mineral fertilizer and excess runoff (Al-Khaisi 2001).

Farmers can also use biomass as an organic alternative to chemical fertilizer to minimize nutrient pollution levels. Biomass is simply plant life that can be obtained from outside sources, such as nearby foliage or compost sites. Biomass contains a lot of nutrients essential for crop growth, so when it is distributed on the field, the crops can yield higher numbers (Enger and Smith 2016). In Brussels, Belgium, a man named Sidi Toure struggled to maintain his four hectare farmland and was able to only plant every other year because of lack of soil quality. He was losing significant profit, so he decided to utilize the practice of natural regeneration. Similarly, to the use of leaf biomass, he used the natural plant life of trees on his farmland to maintain the health of the soil. The foliage from the trees that he previously cut down could now grow and be utilized for soil regeneration. Sidi now has an annual rise in yield (State News Service 2019).

While obtaining adequate biomass to make an impact may be difficult for some farmers, there is one natural source of nitrogen and phosphorous that is readily available and abundant in the Midwest, that is, animal manure. In 2015, the US Department of Agriculture reported that animals at feeding operations produce 335 million tons of manure annually in the United States, and that is just in dry weight. This is compared to the 7 million tons Americans produce in dry weight each year. Main (2015) states how, before modern farming, "The manure these animals produced was typically used to fertilize crops grown at the same or nearby farms, which were then used to feed the animals, creating a semi-sustainable feedback loop". This changed with the rising popularity of chemical fertilizers due to greater ease of transporting and handling and their smelling better. Today, almost all manure sits in lagoons to fester, occasionally leaking out and contaminating groundwater and local watersheds. Rather than letting this nutrient-rich substance stagnate in plastic-lined lagoons, agricultural workers could possibly begin to use naturally available manure in their soils (Main 2015). Upon analyzing the effects of manure fertilizer on soil quality, crop growth, and erosion, the findings showed that manure has a significant value in reducing runoff and erosion and has a residual benefit for runoff and erosion that would persist for at least the next three cropping seasons. Additional soil quality benefits were observed regarding soil bulk density, soil organic matter, and pH (Koelsh 2017).

While there is increased demand for more organic farming methods, some farmers will inevitably use inorganic fertilizer due to economic constraints. In this case, a new solution has to be devised using additional farming techniques in order to control the nutrient pollution they will produce. The land could survive with the use of applied fertilizer as long as there is a focus on maintaining the soil well and using land structure techniques to reduce runoff into local watersheds. As soil degrades and erodes due to poor soil management, fertilizer loses its ability to further

percolate in the soil and begins to move freely through the land into the waterways. The techniques farmers could use to better maintain their soil include using organic matter to mulch soil, reducing tillage, and making specific landscaping to control runoff (Enger and Smith 2016).

The best solution to decrease soil degradation is to reduce the practice of tilling or to eliminate it altogether. Tillage involves the mechanical agitation and overturning of soil to prepare it for seeding (Enger and Smith 2016). Tilling is normally used for weed suppression, turning over cover crops and forages, seedbed preparation, soil aeration, burying heavy crop residue, leveling the soil, incorporating fertilizer into the root zone, and activating pesticides (Al-Khaisi 2004). While tilling does offer some immediate benefits to farmers, in the long run, it can lead to the breakdown of soil structure and increase erosion. As aforementioned, the significant soil erosion and the dumping of nitrogen- and phosphorus-rich sediment have detrimental effects on the Gulf of Mexico dead zone. However, it can also have a negative impact on farmers, too. Al-Khaisi, professor of soil management at Iowa State University, elaborates on these harms:

> There may even be some initial loss of productivity with moderate levels of erosion. With frequent tillage sustained over a couple years, topsoil loss begins to exceed replacement. In time, the soil is in danger of yield setbacks due to organic matter and nutrient loss as well as the damage done to the soil's physical properties (Al-Khaisi 2004).

Conventional tillage can cause soil erosion, lowering of soil quality by fracturing, and disrupting soil structure (Al-Khaisi 2004). Reducing tillage not only is in the best interest of the Gulf's ecosystems and communities but also is vital for the long-term yields and soil quality in agriculture. According to one UN official, most of the world's topsoil could be eroded within the next 60 years with the current rates of erosion (Arsenault 2014). The USDA's Natural Resources Conservation Service reports that Iowa has lost an average of 17.272 cm of topsoil since 1850 (Smith 2017). This may not seem significant, but to give more perspective, it takes nearly 1000 years to generate just 3 cm of topsoil (Arsenault 2014). A study from the Environmental Working Group by Cox et al. (2011) states how a great deal of this eroded soil in the Midwest, choked with full of N and P from chemical fertilizers, "flows downstream to the Gulf of Mexico, contributing to the largest dead zone in U.S. coastal waters and the second largest in the world." Clay Mitchell of Buckingham, IA, grower and Harvard biomedical engineer estimates that "American farmland has lost half of its topsoil and organic matter, and tremendous productive potential" (Smith 2017). This leads to significant yield decline and a loss of profits for farmers, with some estimations saying that the 17 cm loss of topsoil has led to 10 bushels per acre less of corn product (Smith 2017).

There is also some evidence to show conventional tillage has negative effects on beneficial soil microbe life. In the Appalachian Mountains, several plant and soil scientists studied the effects of tilling versus no tilling on cropland to determine which was better for soil microorganisms. The study revealed that the microbial counts were higher and more diverse in the areas with no tillage because they had

healthier soil to thrive in. The experiment included the importance of microbe communities.

> Maintaining the complexity and diversity of soil microorganisms is critical to sustain soil fertility, because soil microbes mediate the biogeochemical cycles of C and N, as well as serve as an important reservoir for plant nutrients (Wang 2017).

Microbes are necessary for land sustainability by acting as natural nutrient producers. The study included that the practice of no tilling reduced the runoff ratio by 64.9% when compared to conventional tilling (Wang 2017).

The structure of the land can also reduce water flow significantly. Two specific styles of farming that control runoff include contour and strip farming. Contour farming tills the land at right angles and creates ridges that act as small dams to prevent water from running down hills (Enger and Smith 2016). Strip farming does not change the land slope and instead focuses on different crop types. In this method, strips of different kinds of crops are alternated because some plants take up more water and nutrients than others. A plant such as corn could be paired with soybeans to retard the flow of water, reducing erosion and allowing more water to sink into the ground (Enger and Smith 2016).

These methods are certainly more sustainable and beneficial for the environment, but there are economic considerations. Many reasons farmers chose inorganic methods and high tillage techniques are for convenience and to maximize profits. When you go to a grocery store and see higher prices for organic foods, it is because organic farming typically costs more. There are several reasons for this, including the costs of more labor, higher fertilizer prices, higher prices to transport organic fertilizer, getting USDA certified, and less government subsidies (Fox News 2012).

Farmers often do not choose to switch to organic farming because it is more expensive than their conventional practices, but according to studies done on comparing the two, this common-held belief may not be entirely accurate. Uri (2000) explains that after analyzing multiple experiments through the compilation of the data, the cost of conventional farming is not any different than conservation farming. He analyzed the yield, fertilizer costs, pesticide costs, seed costs, production costs, and machine costs and came to the conclusion that the costs is dependent on the type of conservation practices and type of crop. Despite the data, he infers that farmers should still utilize conservation practices due to the benefits they have on long-term soil quality. Uri explains "if agricultural output prices are increasing or are expected to increase over time, a more soil-conserving practice will be adopted, all other things equal, since the value of returns associated with soil loss will be higher". He sees the future economic loss if the issue of soil degradation is not addressed. Farmers not motivated to reduce nutrient pollution for the sake of the cause can be encouraged to switch to conservation methods due to the alarming depletion rates of soil.

However, in the long term, there can be benefits to converting to more sustainable farming methods. Like all markets, the more mass-produced organic farming becomes, the lower the costs will be. As environmental concern continues growing

in America, government subsidies for low-pollution farming could very well begin to take place. In the long term, conservation tillage could be of significant economic benefit. It is widely known that the rich topsoil in the Midwest is getting rapidly depleted, and as the fruitful soil erodes and dumps into the rivers, profits will follow suit (Enger and Smith 2016).

While government action concerning the dead zone in the Gulf of Mexico has largely been absent, the Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA 2015) have created numerous initiatives to address both point and nonpoint sources of nutrient pollution. Under the 1972 Clean Water Act, those who release nitrogen and phosphorus from point sources must have received a National Pollutant Discharge Elimination System (NPDES) permit from either the state or the EPA (Fox et al. 2017). This permit places limits on the quantity and concentration to which nutrient pollutants can be released into surface waters. Thus, the NPDES permit ensures that water bodies are clean enough to meet water quality benchmarks by limiting the amount of point source nutrients that slip into water basins.

Compared to point sources, nonpoint sources are much harder to regulate because the nutrient pollution cannot be attributed to a specific location. However, the EPA and USDA are still organizing efforts to limit nutrient pollution from nonpoint sources by providing monetary incentives to farmers and states. The USDA has created several programs to combat nutrient pollution through incentives, including the Conservation Stewardship Program (CSP) and the Environmental Quality Incentives Program (EQIP). Additionally, as a part of the Clean Water Act, the EPA was awarded a $160 million annual grant, which is used to aid pollution reduction efforts at the state level. Despite efforts by the EPA and USDA to reduce nutrient pollution, their programs also create major problems, especially economically. In particular, stricter regulations on the amount of wastewater that can be released drive up the price of utilities, which has implications for taxpayers and may not be worth the added cost (Fox et al. 2017).

Consumers can also play a role in mitigating the effects of dead zones. While it is easy to step back and critique today's agricultural workers and their practices, one must keep in mind that agricultural supply is ultimately tailored to meet the demand of the consumers. While all the people in America need food, our patterns in what we choose to consume and our patterns with consuming ultimately dictate the supply of food. There are many ways the consumers can begin to encourage better farming practices that help our planet, from the fields in Iowa to the depths of the Gulf of Mexico. One way this can be achieved is by choosing to waste less food. According to the United States Department of Agriculture, 31% of food is wasted at the retail and consumer level, the equivalent of $131 billion in food (USDA 2015). Even more food waste occurs at the manufacturing level. They state how "the land, water, labor, energy and other inputs used in producing, processing, transporting, preparing, storing, and disposing of discarded food. . .generate impacts on the environment that may endanger the long-run health of the planet" (USDA 2015). Another way to promote more sustainable agriculture is to choose to eat food that is organically grown with soil conservation in mind. Creating a greater market demand for food

that releases less nitrogen and phosphorous into rivers and causing dead zones will ultimately lead to a greater supply of those foods. If practices are refined and mass-produced, the profit from growing organic can possibly become comparable to inorganic farming. Consuming less meat and avoiding the use of corn-to-ethanol biofuel is another way to mitigate the environmental impacts of our current agricultural system. Currently, 36% of the calories produced by the world's crops are used for animal feed, and only 12% of those feed animals will ultimately contribute to the human diet (Cassidy et al. 2013). Another 4% is used for biofuels such as ethanol. The Institute on the Environment states that even "small shifts in our allocation of crops to animal feed and biofuels could significantly increase global food availability". This increase in food supply could allow farming areas to focus more on environmental quality when growing produce and less on maintaining extremely high yields to meet the American demand. Finally, in America anyone can choose to be an activist and use their voice and voting power to promote more sustainable and environmentally friendly policies and practices.

Dead zones are multifaceted ecological phenomena with widespread implications. Combatting dead zones in the Gulf of Mexico requires input from many parties. Federal legislation may aid in a quicker turnaround for the major contributors to the dead zone. Involvement from fertilizer companies is also required to ensure proper farming practices. A community effort is needed to combat the hypoxic zones along coastal areas, including the mentioned dead zone in the Gulf of Mexico. Population growth requires increased food production, but this does not justify harmful practices. For example, with the wide range of corn products used, from corn syrup to cow feed, this crop and others should be treated with sustainable practices in mind. In addition, extra precaution should be taken in the tributaries that feed into the Mississippi River and, ultimately, the Gulf of Mexico to ensure that green belts are maintained to enhance soil retention and nutrient absorption. All the people living and all the farming and industry groups operating around the Mississippi River watershed should be properly informed about needed sustainable practices.

17.4 Conclusion

The excessive influx of nitrogen and phosphorous from plant agriculture is a contributing factor toward the development of a dead zone. In time, the increased algal blooms decrease the oxygen available in the water and lead to hypoxia that decreases the biodiversity of the affected body of water. These nutrients are shown to carry into areas such as the Gulf of Mexico and the Chesapeake Bay from tributaries that drain runoff containing fertilizer and manure, which can be linked to non-sustainable farming practices. Due to the increase in agriculture since the baby boom, these dead zones have grown, and action needs to be taken to halt this growth. There are many alternative farming practices that can help mitigate this problem such as the use of natural fertilizer instead of chemical, varying the plant type used, crop rotation, the reduction of tilling, and contour and strip farming. In

addition, the less food wasted by consumers will impact the suppliers trying to meet the demands. Federal legislation and farmer education can also be influential in the change to more sustainable farming practices. Overall, the dead zones affect human health and quality of life due to toxins leaching into the ground and draining into surface water bodies where they are bioaccumulated by fish. The solution is to change to more sustainable farming methods.

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